Robust statistical method in a single species age-structured state-space assessment model

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Summary

Robust statistical methods are useful to reduce the influence of extreme outlying (potentially wrong) data points in all statistical catch-at-age models. A common choice is to substitute the Gaussian distribution with a mixture distribution between a Gaussian and a heavy tailed distribution. In state-space assessment models robust statistical methods can in addition be useful to allow sudden unusual changes in recruitment or in fishing mortality.

Introduction

Single-species and age-structured fish stock assessments remain the primary tool for managing fish stocks at ICES working groups. The state-space assessment model class is increasingly being used as an alternative to (semi) deterministic procedures and to full parametric statistical catch-at-age models. Compared to the deterministic procedures it solves a list of problems originating from falsely assuming catches at age are known without errors, and it allows quantification of uncertainties of estimated quantities of interest. Compared to full parametric statistical catch-at-age models the state-space assessment model avoids the problem of fishing mortality being restricted to a parametric structure (e.g. multiplicative), and problems related to having too many model parameters compared to the number of observations. The distribution of change between time steps is part of the model formulation in state-space models and the model parameters are estimated from the entire data set, so if an unusual large change occur (e.g. in recruitment) then the distribution should be flexible enough to allow it, or the model estimate will be too conservative.

Materials and Methods

A state-space age-based assessment model is implemented, which is similar to a frequently used assessment model (Nielsen and Berg 2014), but uses a distribution that allows extremes. The distribution is constructed as a mixture distribution between a Gaussian and a heavy tailed distribution. This mixture distribution is then applied in 1) the observational likelihood to reduce the effect of extreme observations, 2) in the recruitment process to allow for sudden large recruitment events, and 3) in the fishing mortality process to allow for sudden large changes in the fishing pattern. A simulation study is conducted to evaluate the approximation used to make the computations for the state-space assessment model feasible. Finally the different configurations of the model are applied to North Sea Haddock data, where previous assessments have estimated extreme recruitment events. The different settings 1) 2) or 3) correspond to different interpretations of the system, and these are compared.

Results and Discussion

State-space assessment models can pick up on large sudden changes in fishing mortality or recruitment, as long as an appropriate process model is formulated. Using a robust mixture distribution in situations where no sudden large changes occur will result in a little added uncertainty, but using a non-robust method in cases where a sudden large change occur can result in biased estimates (around the change) and inflated uncertainty for the entire estimated process. The estimation methods may need to be changed depending on the model. The Kalman filter is only appropriate for linear Gaussian models, but also the Laplace approximation can become inaccurate e.g. if the problem becomes too severely non-convex. In such situations simulation based methods can be used to validate the results. The practice of allowing extreme events in different parts of the model (observations, recruitment, and fishing mortality) is useful to reveal where model assumptions are constraining, and to illustrate their consequences.

References

Anders Nielsen and Casper W. Berg. 2014. Estimation of time-varying selectivity in stock assessments using state-space models. Fisheries Research, 158:96-101.

Figure 1: A time series with sudden large jumps estimated via a purely Gaussian state-space model and a model where the process increments follow a a robust mixture distribution.